

Patent Application
Docket #52663-00007
MAXM-337

CERTIFICATE OF MAILING BY EXPRESS MAIL	
"EXPRESS MAIL" Mailing Label No. <u>EV 264277636</u>	
Date of Deposit: <u>6-20-03</u>	
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Title: SYSTEM AND METHOD FOR USING AN OUTPUT
 TRANSFORMER FOR LASER DIODE DRIVERS

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TECHNICAL FIELD OF THE INVENTION

The present invention relates to an improved laser diode driver integrated circuit, and in particular to a laser diode driver integrated circuit having an improved output stage.

A majority of laser diode driver integrated circuits (ICs) for optical transmission can be broadly divided into two categories. The first category includes devices using direct modulation. This is generally used for short distance transmission in which a laser diode driver IC is used to directly drive a laser diode module with a drive current supplied by the laser diode driver IC. The second category includes devices which generally use external modulation. These are commonly used for long-distance transmission in which, for example, an electroabsorption (EA) modulator driver IC is used to drive an electroabsorption (EA) modulator module. In both of these categories, laser diode driver ICs can be found in both die forms in which the IC is assembled inside the laser module, and in packaged forms in which the IC is assembled outside of the laser module and connected by a transmission line.

Due to the need for ever increasing data transmission rates, the use of conventional laser diode driver integrated circuits results in numerous signal quality problems. In addition, convention laser diode driver integrated circuits consume a high amount of power due to the need for high

supply voltages. Thus there is a need for laser diode driver integrated circuits that provide improved output signal quality as well as lower power consumption.

SUMMARY OF THE INVENTION

5 One embodiment of the present invention is directed to a laser diode driver output stage for driving an associated laser diode device. The laser diode driver output stage includes a driver circuit having at least one input node, a positive output node, and a negative output node. The
10 driver circuit is adapted to receive an input data signal at the at least one input node and provide an output signal to at least one of the positive output node and the negative output node in response to the data signal. The laser diode driver output stage further includes a transformer having
15 a positive terminal of a first side coupled to the positive output node of the driver circuit, a negative terminal of the first side coupled to the negative output node, and a positive terminal of a second side coupled to the positive output node. The laser diode driver output stage further
20 includes a bias current generator coupled to a negative

terminal of the second side of the transformer, the bias current generator providing a bias current to the negative terminal of the second side, and the transformer adapted to isolate the bias current from fluctuations in the output signal, whereby the output signal and bias current are provided to the associated laser diode device.

Another embodiment of the present invention is directed to a method of providing an improved drive signal from a laser diode driver output stage to a laser diode device, the method comprising the steps of receiving an input data signal at at least one input node of a driver circuit, providing an positive output signal from the driver circuit to a positive output node in response to the data signal, and providing a negative output signal from the driver circuit to a negative output node in response to the data signal. The method further includes the steps of receiving the positive output signal at a positive terminal of a first side of a transformer and a positive terminal of a second side of the transformer, receiving the negative output signal at a negative terminal of the first side of the transformer, and providing a bias current to a negative

terminal of the second side of the transformer from a bias
current generator. The method further includes the step of
isolating the bias current from fluctuations in at least one
of the positive output signal and the negative output
5 signal, whereby the output signal and bias current are
provided to the laser diode device.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the method and
apparatus of the present invention may be obtained by
10 reference to the following Detailed Description when taken
in conjunction with the accompanying Drawings wherein:

FIGURE 1 illustrates an output stage of a conventional
laser diode driver integrated circuit (IC) and an associated
laser diode;

15 FIGURE 2 illustrates an output stage of a laser diode
driver integrated circuit (IC) in accordance with an
embodiment of the present invention and an associated laser
diode;

20 FIGURES 3 illustrates an output current eye diagram of
a conventional laser diode driver integrated circuit; and

FIGURES 4 illustrates an output current eye diagram of laser diode driver integrated circuit having a transformer and an RC network in the output stage in accordance with the principles of the present invention.

5 DETAILED DESCRIPTION OF THE INVENTION

Reference is now made to the Drawings wherein like reference characters denote like or similar parts throughout the various Figures. Referring now to FIGURE 1, an output stage of a conventional laser diode driver integrated circuit (IC) and associated laser diode is illustrated. The output of a conventional laser diode driver IC 102 is connected to a laser diode 104. The conventional laser diode driver IC 102 includes a conventional laser diode driver integrated circuit output stage 106 therein.

15 The conventional laser diode driver integrated circuit output stage 106 comprises a pre-driver circuit 108 and a conventional driver circuit 110. During operation, the pre-driver circuit 108 provides differential input data signals (IN+,IN-), representative of the data signal that is desired
20 to be transmitted by the laser diode 104, to the

conventional driver circuit 110. In response to the differential input data signals (IN+,IN-), the conventional driver circuit 110 provides a modulated output drive signal to the laser diode 104, which generates an optical output data signal that is representative of the differential input data signals (IN+,IN-).

The conventional driver circuit 110 of the conventional laser diode driver integrated circuit output stage 106 typically comprises an output switch architecture in the form of a bipolar junction transistor (BJT) differential pair configuration. The conventional driver circuit 110 of FIGURE 1 includes a first transistor 112 and second transistor 114 whose respective emitter nodes are joined together and biased by a modulation current source 116 providing a modulation current (Imod), which is further connected to a low reference supply voltage (Vee). The collector node of the first transistor 112 is connected to a negative output terminal 118 of the conventional laser diode driver IC 102 through a dummy diode 128. The negative output terminal 118 is further connected to high reference supply voltage (Vcc) through a connection having a wire bond

inductance 132. The collector node of the second transistor 114 is connected to a positive output terminal 120 through a damping resistor 122.

5 The conventional driver circuit 110 further includes a bias current source 124 for providing a bias current (I_{bias}) to a bias current output terminal 126. In addition, the bias current source 124 possesses a parasitic capacitance 130 that acts in parallel to the bias current source 124. The bias current source 124 is further
10 connected to the low reference supply voltage (V_{ee}). The function of the bias current (I_{bias}) is to push the laser diode 104 operating range beyond its threshold value and into the linear region of operation.

15 An anode of the laser diode 104 is connected to the high reference supply voltage (V_{cc}), while a cathode of the laser diode 104 is connected to the positive output terminal 120 through a connection having a wire bond inductance 134. In addition, the laser diode 104 inherently possesses a parasitic capacitance which is shown by a capacitor 136.
20 This parasitic capacitance may be on the order of several picofarads (pF). The cathode of the laser diode 104 is

normally further connected to the bias current output terminal 126 through a ferrite bead 138 functioning as an isolator.

During operation, the aforementioned differential input data signals (IN+,IN-) are provided from the pre-driver circuit 108 to the respective gate nodes of the first transistor 112 and the second transistor 114. The modulation current source 116 provides the modulation current (Imod) that is modulated in proportion to the transmitted data signal, while the bias current source 124 provides the bias current (Ibias) to bias the laser diode 104 just prior to oscillation. In response to the differential input data signals (IN+,IN-), the differential pair configuration provides the modulated output drive signal to the negative output terminal 118 and the positive output terminal 120 for driving the laser diode 104.

In order to drive a laser diode 104 to transmit data at higher rates, for example, a rate of 10Gbits/sec or greater, a modulation current of 60mA, and a bias current of 60mA is typically necessary. In addition, it is necessary for the output current falling time/rising time

(tr/tf) transition to be at as high a rate as possible, typically on the order of 20-30 picoseconds (ps).

5 In order to handle the high current requirements and the high speed pulse requirements, the conventional laser diode driver IC 102 is usually packaged inside a laser module driver in a die form, and wire bonded onto the laser diode 104. When packaged in this form and with the
10 aforementioned drive requirements, the wire bond inductance 132, 134 and parasitic capacitance 136 of the laser diode 104, causes ringing on the output current waveform with a frequency approximately equal to the bit rate of data transmission. As a consequence of this ringing, a large amount of overshoot/undershoot, small eye opening of the eye diagram, and an increase in deterministic jitter is present.

15 The aforementioned damping resistor 122, typically having a value of several ohms to several tens of ohms, functions to suppress such ringing. However, the damping resistor 122 causes degradation of the rising time/falling time (tr/tf) of the output current waveform, as well as a
20 shortage of headroom of the second transistor 114 when used at low supply voltages. The ferrite bead 138, placed

between the positive output terminal 120 and the bias current output terminal 126, acts as an isolator between fluctuations in the modulation current and the bias current. Without the ferrite bead 138, the parasitic capacitance 130 of the bias current source 124 will fluctuate due to the ringing generated in the modulation current waveform as a result of wire bond inductances. The fluctuation in the parasitic capacitance 130 results in fluctuations in the bias current (I_{bias}), which causes further degradation of the output current waveform.

The conventional laser diode driver integrated circuit output stage 106 of FIGURE 1 possesses several disadvantages. At high data transfer rates, such as at bit rates greater than 10Gbits/sec, the parasitic capacitance and inductance of ferrite bead 138 impacts the optical characteristics of the laser diode 104. In addition, it is desirable from a packaging standpoint to have both the output switch stage and bias current source 124 inside the integrated circuit package.

When the power supply voltage is at a high level, e.g. greater than 5 volts, the output switch stage and bias

current source 124 can be isolated by cascading the bias
current source 124. However, with a low power supply
voltage, e.g. 3.3 volts this is difficult to achieve, as it
is difficult to meet both the requirement for a large drive
5 current (more than 60mA) and adequate collector-emitter
voltage headroom when the bias current circuit is configured
with bipolar transistors.

Referring now to FIGURE 2, an output stage of a laser
diode driver integrated circuit (IC) in accordance with an
10 embodiment of the present invention and an associated laser
diode is illustrated. The laser diode driver IC 202 is
connected to a laser diode 104 for providing a modulated
output drive signal. The laser diode driver IC 202 includes
a laser diode driver integrated circuit (IC) output stage
15 206 that includes a pre-driver circuit 208 and a driver
circuit 210 comprised of an output switch architecture. In
the presently described embodiment, the driver circuit 210
of the laser diode driver integrated circuit output stage
206 comprises a bipolar conjunction transistor (BJT)
20 differential pair configuration functioning as a
differential amplifier.

The driver circuit 210 of FIGURE 2 includes a first switch transistor 212 and a second switch transistor 214 whose respective emitter nodes are joined together and biased by a modulation current source 216 provided a modulation current (I_{mod}). The modulation current source 216 is further connected to a low reference supply voltage (V_{ee}). The collector node of the first switch transistor 212 is connected to a negative output terminal 218 of the laser diode driver IC 102 through a dummy diode 228. The negative output terminal 218 is further connected to high reference supply voltage (V_{cc}) through a connection. This connection will have an inherent wire bond inductance 132. The collector node of the second switch transistor 214 is connected to a positive output terminal 220.

The driver circuit 210 further includes a bias current source 224 for providing a bias current (I_{bias}) whose function is to push the laser diode 104 operating range beyond its threshold value and into the linear region of operation. The bias current source 224 possesses a parasitic capacitance 230 that acts in parallel to the bias current source 224.

In accordance with the present invention, a transformer 232 is connected within the integrated circuit output stage 206. It should be understood that the transformer 232 may be comprised of an on-chip transformer fabricated on the die of the laser diode driver integrated circuit output stage 206. Alternately, the transformer 232 may be comprised of any other suitable transformer either external to or internal to the integrated circuit package.

Still referring to FIGURE 2, a negative terminal of a primary side (L_p) of the transformer 232 is connected to the collector node of the first switch transistor 212 through an RC network 238, and a positive terminal of the primary side (L_p) of the transformer 232 is connected to the collector node of the second switch transistor 214. In the present embodiment, the RC network 238 is comprised of a capacitor 240 and resistor 242 connected in series, although it should be understood that any suitable RC network can be used. A positive terminal of a secondary side (L_s) of the transformer 232 is connected to the collector node of the second switch transistor 214, and a negative terminal of the secondary side (L_s) of the transformer 232 is connected to

the bias current source 224. The bias current source 224 is further connected to the low reference supply voltage (Vee).

Further, a primary side resistor 234 is connected in parallel between the positive and negative terminals of the primary side (Lp) of the transformer 232, and a secondary side resistor 236 is connected in parallel between the positive and negative terminals of a secondary side (Ls) of the transformer 232.

The anode of the laser diode 104 is connected to the high reference supply voltage (Vcc), while the cathode of the laser diode 104 is connected to the positive output terminal 220 through a connection having a wire bond inductance 134. In addition, the laser diode 104 possesses a parasitic capacitance 136 of several picofarads (pF).

During operation, differential input data signals (IN+,IN-) are provided from the pre-driver circuit 208 to the respective gate nodes of the first switch transistor 212 and the second switch transistor 214. The modulation current source 216 provides the modulation current (Imod) that is modulated in proportion to the transmitted data

signal, while the bias current source 224 provides a bias current (I_{bias}) to bias the laser diode 104. In response to the differential input data signals ($IN+$, $IN-$), the differential pair configuration provides a modulated output drive signal to the negative output terminal 218 and the positive output terminal 220 for driving the laser diode 104.

During the driving of the laser diode 104, an output current, comprised of the modulation current and bias current ($I_{mod}+I_{bias}$), is output from the positive output terminal 220. Due to the parasitic capacitance 136 of the laser diode 104 and the wire bond inductance 134 at the positive output terminal 220, ringing occurs at the edges of the output current waveform.

The use of the transformer 232 and RC network 238 between the positive and negative sides of the output switch in accordance with the principles of the present invention produces a transient current flow in the opposite direction of the ringing of the output current waveform. This results in a decrease in the rising times/falling times (t_r/t_f) of the output current waveform transitions. In addition, the

tr/tf transition edge of the transient current generates an electromotive force (V_{ip}) on the primary side of the transformer 232, resulting in a suppression of the ringing in the output current waveform. It should be understood, that the characteristics of the transient current can be adjusted by an appropriate choice of the network time constant of the RC network 238, which enables adjustment of the overshoot/undershoot caused by the output current tr/tf and ringing.

The transformer 232 and RC network 238 of the present invention also provides for improved isolation of the bias current from output current waveform fluctuations. When current is fed to the laser diode 104, transient current flowing through the RC network 238 results in the edge of the rising time/falling time (t_r/t_f) waveform transitions generating an electromotive force V_{ip} on the primary side (L_p) of the transformer 232. As a result of the electromotive force V_{ip} , a corresponding electromotive force V_{is} is generated at the secondary side (L_s) of the transformer 232 connected to the bias current source 224 in proportion to the coupling factor K of the transformer 232.

The resultant electromotive force V_{is} is generated in the inverse direction as that of the abrupt transition of the waveform at the positive output terminal 220. As a result of the generation of the electromotive force V_{ip} , fluctuation of the parasitic capacitance 230 of the bias current source 224 caused by the output current waveform is suppressed.

The secondary side resistor 236, placed in series with the secondary side of the transformer 232 and the bias current source 224, functions as a damping resistor to suppress ringing generated by the parasitic capacitance 230 of the bias current source 224 and the inductance of the secondary side (L_s) of the transformer 232.

It should be understood that numerous modifications may be made to the embodiment of FIGURE 2 without departing from the spirit of the present invention. Although the invention of FIGURE 2 is illustrated using a bipolar junction transistor (BJT) pair architecture as a driver circuit, any other suitable output switch architecture may be used, such as those using field effect transistors (FETs), CMOS devices, etc. In addition, although the driver circuit of

FIGURE 2 is illustrated through the use of a single stage emitter-coupled differential amplifier, a multi-stage differential amplifier having a transformer in its output stage may be used without departing from the spirit of the invention. The principles of the present invention are also applicable to output stages having both single-ended and differential outputs and/or inputs.

Although the embodiment of FIGURE 2 illustrates the use of a laser diode driver IC to drive a laser diode, the principles of the present invention are equally applicable to an electroabsorption (EA) modulator driver IC used to drive an electroabsorption (EA) modulator module for long distance transmission. Additionally, the principles of the present invention are applicable to any driver device used to drive a load.

Referring now to FIGURES 3, an output current eye diagram of a conventional laser diode driver integrated circuit is illustrated. As illustrated in FIGURE 3, a large amount of ringing and current fluctuation is present in the output current signal. FIGURE 4 illustrates an output current eye diagram of laser diode driver integrated circuit

having a transformer and an RC network in the output stage in accordance with the principles of the present invention. As can be seen in FIGURE 4, ringing and current fluctuation in the output current signal has been greatly reduced.

5 The improved laser diode driver integrated circuit output stage of the present invention provides several benefits over conventional laser diode driver integrated circuits. The laser diode driver IC of the present invention allows for a lower supply voltage (e.g. $V_{cc}=3.3V$ typical) over that of a conventional laser diode driver IC, 10 resulting in lower power consumption. In addition, output current ringing caused by parasitic capacitance of the laser diode and the wire bond inductance of the output pad can be greatly reduced without resulting in an increase in the 15 rising times and the falling times of the output waveform transitions. Additionally, a reduction in the deterministic jitter and eye opening in the eye diagram of the output current is achieved.

20 The present invention provides for the further benefit of reducing the impact of the output current switch stage generating the modulation current upon the bias current

source generating the bias current, even when the output switch stage and the bias current source are connected within the integrated circuit.

Although a preferred embodiment of the method and apparatus of the present invention has been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it is understood that the invention is not limited to the embodiment disclosed, but is capable of numerous rearrangements, modifications, and substitutions without departing from the spirit of the invention as set forth and defined by the following claims.